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EXPLORING SUSTAINABLE FAÇADE SOLUTIONS: A CASE STUDY OF RESIDENTIAL BUILDINGS IN ZAKHO, IRAQ

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ABSTRACT

This paper underscores the pressing need to address resilience and sustainability in the face of constant challenges, environmental threats, and rapid changes in living conditions. In response, an interdisciplinary and holistic approach is deemed crucial, with engineering science playing a pivotal role in adapting to global conditions. The focus of this research is on identifying sustainability-related parameters for sustainable façades during the preliminary design phase and assessing existing decision support tools. Through a comparative analysis of methods in architectural design, environmental engineering, and structural design, the authors aim to enhance the understanding of sustainable architectural design concepts. The study specifically examines three façades in Zakho, Iraq, employing specific criteria such as diverse building types, locations, and design timelines. The last three steps of the preliminary design stage are emphasized for façade design optimization, a critical aspect influencing overall building performance and sustainability parameters. Various methods, including forecasting and backcasting, are considered alongside post-occupancy evaluation tools, incorporating factors like window-to-wall ratio, shadow elements, material selection, and natural lighting techniques. The research findings highlight the significance of a window ratio between 60% and 75% in the city's buildings, particularly given the prevalent single-facade architecture. Material selection emerges as a crucial factor impacting thermal performance, and strategic placement of insulation materials is identified as vital for optimizing energy efficiency. The article underscores the importance of informed decisions in choosing a building's location, initiating with site selection, and educating designers about the environmental implications of building orientation on overall well-being.
Keywords: Sustainable development; architectural design; Energy efficiency; Selection material

I INTRODUCTION

Sustainable development, a principle established towards the close of the twentieth century, entails fostering development that satisfies current requirements while safeguarding the capacity of future generations to fulfill their own needs [1,2]. This philosophy has found application in fields such as architecture and the environment [3,4]. Beyond addressing aesthetic considerations, the design prioritized environmental separation and shielding the structure from external influences [4]. Integral to the structure's overall performance, Facades play a vital role in upholding key attributes like structural integrity, safety, and sustainability [5,6]. These encompass human comfort, durability, and cost efficiency [7]. In the last twenty years, designers have dedicated their efforts to developing facade systems that minimize energy consumption and strive for solutions that prevent future energy leakage [8]. This emphasis is particularly noteworthy due to the facades' crucial role in a building's aesthetics and overall sustainability [9]. Achieving sustainability in buildings involves various methods applied to facades, such as minimizing total mass, optimizing orientation, and reducing surface area [10]. In modern construction, additional strategies focus on substantial energy savings through practices like incorporating natural ventilation, maximizing daylight utilization, deploying smart and adaptive devices for solar and wind energy generation, as well as integrating greenery with facades, and utilizing sustainable materials [11-13].

Engineers collaborate from the initial stages of design to establish a comprehensive facade system in conjunction with specialized contractors [14]. The key determinants for selecting an appropriate design strategy for facades are geographical location and climate[15].

Facades play a pivotal role in influencing energy consumption and comfort standards within a building [16]. Achieving energy efficiency in building systems is now a vital requirement, achieved through smart devices, the integration of plants and facades, sustainable materials, and reliance on natural ventilation and daylight [17, 18]. Studies have shown that double facades can notably decrease heating, cooling, and lighting energy demands [19]. Compared to traditional facades, they can reduce heating loads by up to 90% and cooling loads by 30% [20]. In addition to energy savings, double facades enhance thermal insulation, mitigate noise pollution, and contribute to improved air quality through natural ventilation [21].

This study aims to identify sustainability-related parameters, determine key steps for implementing a sustainable design strategy, and evaluate existing decision support tools for the seamless integration of sustainable principles into the overall design process in the city.

Study Area

Zakho is situated in the northern region of Iraq, approximately 50 km northwest of Dohuk, with coordinates 37°08′37.00″N 42°40′54.88″E as shown in Fig.1. Positioned just 8 km from the Turkish-Iraqi border, it serves as a crucial customs point, contributing to its status as a significant commercial hub. The city plays a pivotal role in facilitating trade, serving not only the Kurdistan region but also the central parts of Iraq. With a population of around 260 thousand residents, Zakho stands as a vital center for economic activities in the area.

We selected this city based on its impressive and swift progression, marked by remarkable development. The cityscape stands out for its diversity, reflecting the rapid modernization and infusion of regional cultures. As previously highlighted, the urban landscape encompasses a myriad of buildings featuring distinct facades and a broad spectrum of materials. However, it's worth noting that the application of these materials lacks adherence to specialized engineering methods and often deviates from established standards concerning facade design, material usage, and energy efficiency.

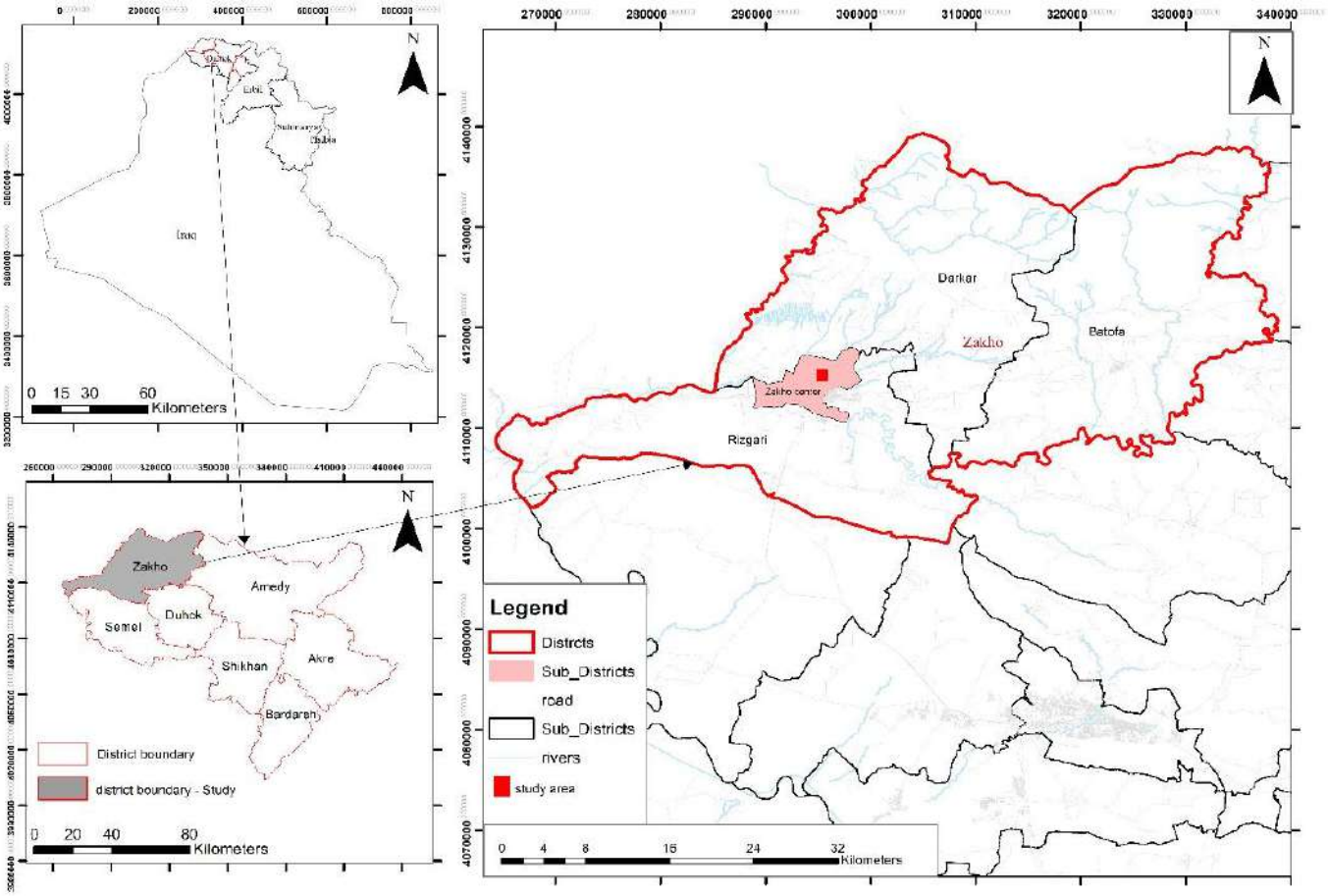

Fig.1 Map of Zakho, displaying the study area

II METHODOLOGY

The study compared decision support methods and tools for sustainable development in architectural design, environmental engineering, and structural design. Utilizing a comprehensive analysis of diverse sources, including journal papers, articles, and books, insights into architectural practices were gathered. In Zakho, residential houses are typically organized in blocks, with single facades for most houses, with exceptions being corner houses with dual faces [22]. The study specifically examined three facades in the city to gain nuanced insights into sustainable architectural design principles. Selection criteria considered diverse building types, locations, and design periods.

The methodology employed in this study is outlined in Fig.2, encompassing several sequential steps. Commencing with an on-site assessment to identify sustainability-façades, the process transitions to the initiation of operations. Subsequently, a thorough evaluation of façade design, encompassing both rehabilitation and demolition aspects, is conducted. This evaluation is categorized into three main components under the umbrella of holistic design. Firstly, the orientation of the building to meet the site's specific needs is addressed. The optimization of the ratio of openings and the selection of materials in alignment with the design style follows suit. The modern purification for natural lighting and integration of architectural elements to achieve deceptive harmony are integral components of this holistic design approach. Continuing within the holistic design framework, considerations are extended to cooling and heating requirements, facade maintenance based on material selection, and aesthetic and physiological aspects catering to residents. Additionally, a comprehensive analysis of total costs, encompassing both short and long-term perspectives, is undertaken. Beyond holistic design considerations, the study incorporates the engineer's knowledge of facade design dimensions and the building owner's cultural perspectives regarding future general costs. Innovative design solutions are explored to maximize the attainable sustainability of facades. This multifaceted methodology ensures a comprehensive and systematic approach to understanding, implementing, and optimizing sustainable facades.

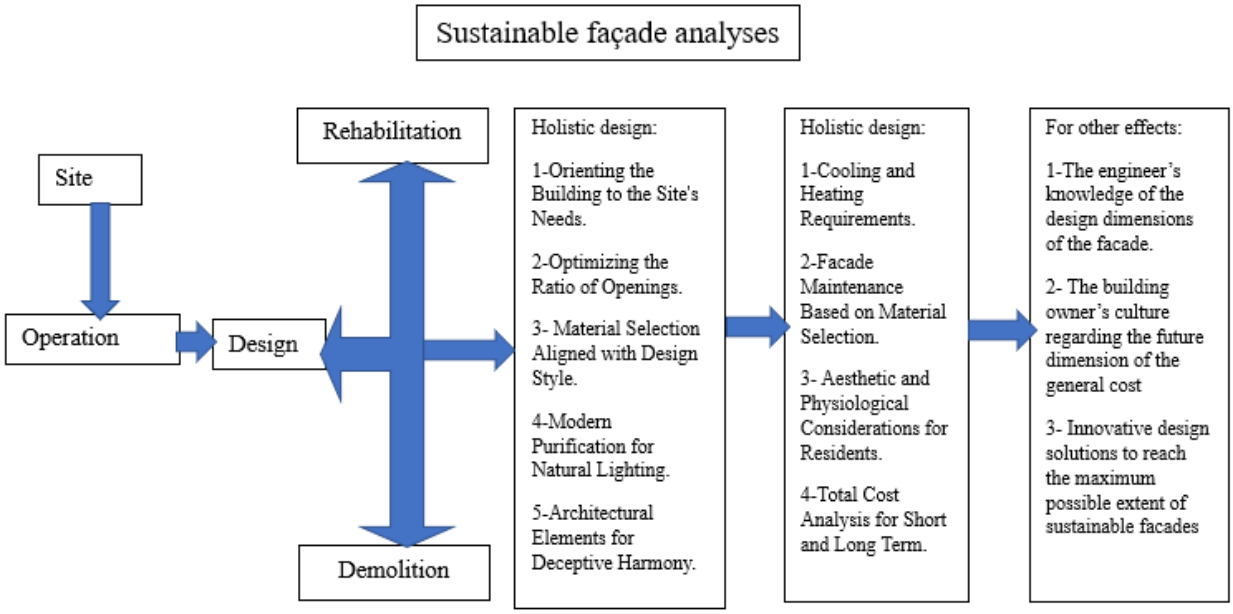
Sustainable façade analyses
Site
Operation
Design
Rehabilitation
Demolition
Holistic design:
1-Orienting the Building to the Site's Needs.
2-Optimizing the Ratio of Openings.
3- Material Selection Aligned with Design Style.
4-Modern Purification for Natural Lighting.
5-Architectural Elements for Deceptive Harmony.
Holistic design:
1-Cooling and Heating Requirements.
2-Facade Maintenance Based on Material Selection.
3- Aesthetic and Physiological Considerations for Residents.
4-Total Cost Analysis for Short and Long Term.
For other effects:
1-The engineer's knowledge of the design dimensions of the facade.
2- The building owner's culture regarding the future dimension of the general cost
3- Innovative design solutions to reach the maximum possible extent of sustainable facades

Fig.2 Schematic illustration of the proposed methodology

Sustainable Façade Criteria

1. Window-to-Wall Ratio

Research confirms that the size and location of building openings significantly affect energy consumption, influencing heating and cooling loads. Previous studies reveal that the opening's location, proportion, and changes in the area directly impact energy usage, albeit with a relatively small effect of approximately 2% [23]. Crucially, the importance of natural lighting extends beyond economic considerations. Empirical studies consistently show that sunlight influences individuals' physiological and health conditions [24]. The assessment of natural lighting should consider its size, shape, and the local climate, affecting building maintenance and energy consumption. Differences in window size and orientation impact heat load and energy transfer, with the location playing a role in northern windows having a greater effect than southern ones [25].

2. Shading Elements

Effective lighting is vital for daily activities, and insufficient lighting can result in visual discomfort, potentially contributing to sick building syndrome symptoms like itching and eye irritation [26]. Poorly designed lighting can also lead to thermal discomfort and glare from natural lighting. Incorporating natural lighting into a building is contingent on its function and the local climate. The design process necessitates thoughtful consideration of both the quantity and quality of natural lighting in the interior [27]. Researchers emphasize that window shades on the facade control light levels, eliminating unwanted light and influencing choices in colors and interior decorations [28]. Shading alternatives play a crucial role in reducing overall energy demand, contributing to energy efficiency in openings, and lowering carbon dioxide emissions [29].

3. Material Selection

Facade materials, encompassing windows, openings, decorations, and architectural elements, are crucial for curbing energy consumption, load, and environmental impact [30]. Studies on glazing, like double electrochromic, triple glazing Lowe, and variants, explore their impact on office building energy performance [31].

In hot climates, research highlights better cooling load reduction with stone over aluminum panels and plaster systems (4% and 1.5% decrease, respectively). Polyurethane board material achieves a 3.8% reduction compared to sandstone with expanded polystyrene [32]. Finishing materials, externally and internally, and heat-insulating materials significantly affect a building's thermal load. Using these in walls and windows enhances thermal performance and solar radiation reflection. For hot climates, the recommended facade is gravel grey stone with a cavity, incorporating mineral fiberglass for improved thermal performance and fire resistance. The study underscores wise material selection and heat-insulating materials for optimal energy efficiency and building safety [33].

4. Natural Lighting Techniques

Efficient lighting design extends beyond energy-saving benefits, positively impacting mood, health, and safety while avoiding negative aesthetic judgments [34]. The availability of natural lighting, particularly in economically and electrically viable areas, is considered a luxurious feature for users. Natural lighting enhances well-being and significantly conserves energy consumption [35]. Designers consistently seek better ways to balance lighting in a space. With increased attention to energy studies, architects are emphasizing sustainable approaches, particularly in areas where electric lighting is expensive. They aim to efficiently utilize natural light to minimize costs and enhance sustainability [36]. The scientific paper concludes that natural lighting is influenced by factors such as the light quantity in a location, the size and location of openings for light entry into a space, and the materials used in these openings.

5. Building orientation

Navigating the orientation of buildings has been a historical challenge for designers, with clear-cut directions like south, southeast, or west in ancient times [37]. Today, urban expansion and diverse environmental factors complicate this task. Designers employ calculations and experiments to discern the optimal approach, considering factors like the need for natural light and the drive for sustainable, energy-efficient design. Establishing explicit standards for building guidelines is challenging due to variations in daylighting standards, climates, and locations [38].

Strategic direction hinges on multiple considerations, ensuring that buildings harness natural light effectively to achieve sustainability and energy efficiency. Geographic and climatic factors play a pivotal role in sustainable and energy-efficient building design [39]. Considering elements such as solar radiation, temperature, wind, precipitation, and humidity is crucial for a holistic approach to building orientation. This comprehensive strategy not only maximizes energy efficiency but also contributes to the well-being of building occupants. To delve into the intricacies of sustainable design, the study considered multiple objective aspects. These included the window-to-wall ratio, integration of shadow elements, material selection, and techniques for maximizing natural lighting. Each elevation was meticulously scrutinized based on these criteria, with a comprehensive evaluation scale ranging from 1 (indicating poor performance) to 10 (reflecting excellent performance). This methodical approach aimed to provide a detailed and nuanced assessment of the sustainable architectural elements present in the selected facades, contributing to a richer understanding of their effectiveness in the context of Zakho's residential landscape.

Table 1: Evaluation Criteria

No	Features	Description
	Window-to-Wall Ratio	Measure the ratio of the total wall area to the window area
2	Shading Elements	The elements used to provide shade, such as overhangs and architectural design.
3	Material Selection	Study and evaluate facade materials in terms of sustainability and effectiveness
4	Natural Lighting Techniques	Examine how the facade utilizes natural lighting for optimal benefit.
5	Building orientation	According to the best city orientation, which it is South.

III RESULT AND DISCUSSION

In the city of Zakho, houses are primarily organized in residential blocks, with each house typically featuring a single facade. However, exceptions arise when a house is situated on a corner, leading to the design of two faces. For this study, we focused on examining four facades within the city, aiming to gain a clearer understanding of the fundamental principles of sustainable architectural design. The selection criteria were based on specific factors such as different building types, locations, and design periods.

The author further investigated various objective aspects, including the window-to-wall ratio, shadow elements, material selection, and natural lighting techniques. This comprehensive analysis contributes to a more nuanced exploration of sustainable architectural practices in the context of Zakho's urban housing landscape.

Case 1:

One elevation house type, two-floor house 150 m^2, locations: new Zakho extend area, designs time: between 2018-2019. Most recently houses have the same floor plan.

Fig.2 House 250m^2 one elevation

No	Features	Description	Evaluation
1	Window-to-Wall Ratio	45% the same oping area in both first and ground floor except the main door in the ground floor	5
2	Shading Elements	Balcony and natural element(tree)	4
3	Material Selection	Cement plaster: Dye: polystyrene cork, which insulates heat and sound is resistant to different weather conditions, and can be painted in different colors.	4
4	Natural Lighting Techniques	Balcony and natural element(tree). Curtain	5
5	Building orientation	South	9

The house's optimal south-facing orientation in the city ensures benefits in both winter and summer. The design integrates effective shading elements and natural lighting techniques, enhancing interior functionality. While material choices align with contemporary trends, there's potential for improvement in their placement. The window-to-wall ratio exhibits a balanced distribution of openings, contributing to a harmonious living space.

Case 2:
Two elevation house type, two-floor house 250 m^2, locations: city center, design time: between 2016-2015.

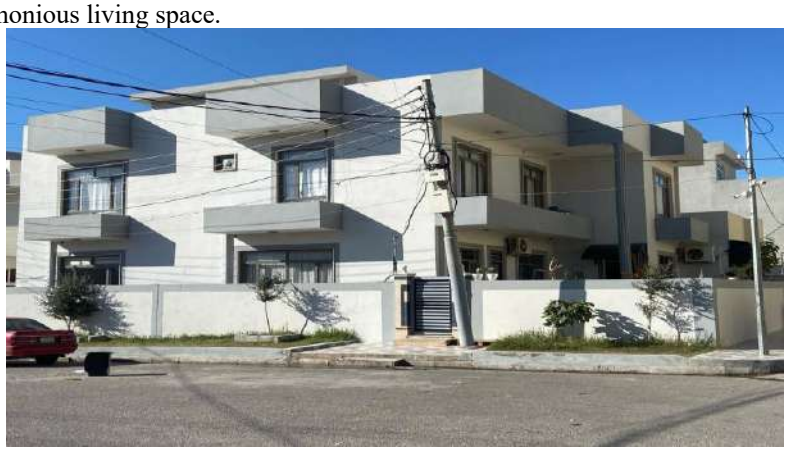

Fig.3 House area 250 m^2 Two elevation

No	Features	Description	Evaluation
1	Window-to-Wall Ratio	30%	4
2	Shading Elements	Balcony and natural element(tree)	3
3	Material Selection	Cement plaster: Dye	2
4	Natural Lighting Techniques	Balcony and natural element(tree). Curtain	5
5	Building orientation	North East	6

The primary issue in this house is its poor aesthetic design and the lack of thoughtful material selection, adversely impacting energy consumption. Despite a north-east orientation, which has potential if utilized effectively, it was not optimally leveraged. Architectural elements like balconies, although present, fail to effectively manage lighting levels. The window-to-wall ratio, however, displays a balanced distribution, contributing to a harmonious living space.

Case 3:

One elevation house type, two-floor house 125 m^2, locations: west of the city center, design time: between 2020-2021.

Fig.4 House 125m^2 One elevation

No	Features	Description	Evaluation
1	Window-to-Wall Ratio	60%	5
2	Shading Elements	Balcony	3
3	Material Selection	Cement plaster: Dye: polystyrene cork, which insulates heat and sound is resistant to different weather conditions, and can be painted in different colors.	2
4	Natural Lighting Techniques	Balcony, curtain	5
5	Building orientation	North	4

Designed primarily for profitable sales, this house type in the city adopts an aesthetic targeting the middle class with architectural elements resembling affluent homes. However, its north-facing orientation exposes it to unfavorable weather conditions in both winter and summer. The design incorporates a few inadequate shading elements and minimal natural lighting techniques. Unwise material choices contribute to varying energy consumption throughout the building's life. Despite these challenges, the window-to-wall ratio is well-distributed, promoting a well-lit living space.

Case 4:
Two elevation house type, two-floor dwelling 250m^2, locations: city center, design time: between 2000-2001.

Fig.5 House 125m^2: House 250 m^2 Two elevation

No	Features	Description	Evaluation
1	Window-to-Wall Ratio	45%	4
2	Shading Elements	Balcony	3
3	Material Selection	Cement plaster: natural stone, marble	7
4	Natural Lighting Techniques	Balcony, curtain	5
5	Building orientation	West	4

A decade ago, city facades displayed material variations. This house has two facades, focusing solely on the design and cladding of the western one. Unfortunately, materials for the neglected northern facade, while thermally insulating, didn't meet operational needs. The ratio of openings is somewhat inadequate, and balcony use for shading lacks effective natural lighting. This indicates room for improvement in the building's design and functionality.

Upon examining existing structures within the city across defined periods, it is evident that residences lack a sustainable facade design, leading to heightened energy consumption and adverse physiological effects on residents. Addressing this challenge necessitates a thoughtful plan that prioritizes analytical studies over theoretical considerations. Despite the time-intensive nature of such endeavors, some fundamental guidelines for designers can be identified. Firstly, the proportion of windows in a building should align with the climatic conditions and the function of the space, ideally falling within a range of 60% to 75%, especially given the prevalence of single-facade homes. Diversifying misinformation elements, beyond just balconies, is crucial. The selection of materials significantly influences thermal performance, emphasizing the importance of strategic placement for insulating materials. Advancements in natural lighting technology and exploration of alternative solutions suitable for similar climates are imperative. The process begins with the building owner's choice of land, highlighting the environmental impact of the built direction on well-being and stressing the need for educating designers in this regard. In essence, mitigating these issues requires a comprehensive and informed approach to redefining the facade design of city homes.

IVCONCLUSION

In conclusion, this research focused on sustainable façade design during the preliminary phase, particularly examining three facades in Zakho, Iraq. A crucial finding highlights the necessity of adapting window proportions to align with climatic conditions and intended space function, recommending a 60-75% window-to-wall ratio. Material selection's impact on thermal performance emerged as a key consideration, emphasizing the strategic placement of insulating materials within the building envelope. The study underscores the need for technological advancements in natural lighting techniques and the exploration of alternative solutions suited to specific geographical climates. Furthermore, the research advocates for the incorporation of various design elements, such as balconies, and the judicious use of misinformation as essential strategies for achieving sustainable façades.The study places significant emphasis on the role of building owners in the early construction stages, highlighting their pivotal role in land acquisition and the selection of the building's orientation.

Additionally, there is a call for increased awareness among designers regarding the environmental implications of their choices, particularly to the built environment's impact on overall well-being. In summary, this study offers practical insights into essential parameters for sustainable façades, emphasizing a holistic approach that considers climatic factors, material choices, and informed decision-making from the outset of the design process. As global efforts toward sustainability intensify, findings from studies like these provide invaluable guidance for architects, designers, and policymakers, facilitating the creation of built environments that are both environmentally responsible and conducive to human well-being.

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